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AN EXTENDED RELIABILITY MODEL FOR GLOBAL LOGISTICS SYSTEMS UNDER UNCERTAIN ENVIRONMENT

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ABSTRACT

This study extends Vidal & Goetschalckx's [19] model, emphasizing on how to add concerns of uncertainties on all players in a global logistics system appropriately. By addressing the tradeoffs between overall system reliability and total cost of a global logistics system, an extension model with two operation modes are proposed. Mode 1 operation aims to seek minimum cost on a target of system reliability; whereas Mode 2 operation concentrates on finding out maximum system reliability on a target of cost. To further examine the feasibility of this extended model, experiments on a simplified four-echelon global logistics structure are done. In short, the experiment results help not only to validate the extended model, but also to highlight the effects of the non-linear relation between system reliability and cost (i.e., the effects resulting from thresholds).To sum up, this study provides not merely an improved quantitative reference model for planning the overall logistics system; the two operation modes are believed to be useful for decision makers in terms of how to balance these two kernel but tradeoff concerns (i.e., overall system reliability and total cost) in a logistics system.

Keywords: global logistics, mathematical model, uncertainty, reliability

1. INTRODUCTION

The ideal logistics management is a fully integration of business processes from consumers toward suppliers, with smooth flows for products, services and information delivery [13]. Gradually, owing to the influence of global economy, the scope of logistics management is no longer limited by the geography. And it is no wonder that companies start to rebuild their logistics systems in an effort to benefit from globalization. However, two characteristics of globalization, namely high uncertainty and complexity, make it hard to coordinate or to integrate all business processes of a global logistics system. What is worse, few studies contribute to build up quantitative models with concerns on both uncertainty and complexity for global logistics management. Consequently, to support the management making better decisions under this global environment with intensive uncertainty, it calls for an efficient mathematical model with thoroughly considerations [18].

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2. LITERATURE REVIEW

2.1 The Models of Global Logistics Systems Design

Due to the global competition and faster product development, an unprecedented number of products are competing in various markets. Despite the benefits of consumers, this phenomenon makes it more difficult for players in a logistics system to predict when and which products will be sold out. Moreover, in industries with highly volatile demand, the costs of such “stockouts” and markdowns will actually exceed the total cost of manufacturing [10]. Thus, having appropriate supply chain (SC) network design or having reliable partners in the logistics system seems to be one of the best practices for ensuring low cost, reliability and quick response of the system [3, 9, 15].

When further investigating how studies take uncertainty or reliability into account in the context of logistics management or supply chain management (SCM), three main themes can be identified. The first one emphasizes on how to illustrate the effects rising from uncertainty, as well as how to find proper strategies in shaping the volatility. Generally speaking, both qualitative and quantitative approaches are applied. For instance, Davis [8], Fisher [10], and Taylor [17] take practical cases as their basis, exploring ways for classifying and ways for solving various types of uncertainty. On the contrary, Anderson, Fine & Parker [1], Chen, Ryan & Simchi-Levi [4], and Chen et al. [5] all contribute in this aspect by utilizing simulation techniques, even though each of them has its own specific focus.

The second research direction is to extend current logistics management in regard to its coverage scope. One typical example is the emerging of reverse logistics management or recovery network models. Not long ago, Fleischmann et al. [12] make a thoroughly review on the quantitative models for reverse logistics, which summarizes and compares how relevant studies identify their frameworks, build up their own mathematical models, and apply on examples or cases.

As for the third theme, it focuses on the value of making mathematical models more dynamic, rather deterministic, due to the increasingly importance of variance (in particular for those rising from uncertainties). In the past, deterministic models dominate the development of mathematical models in logistics management. In general, those deterministic models all hold an implied assumption: “network design and resource deployment in a global logistics system are long-term strategic decisions;” thus, without any doubt, daily variation would not be necessary to be taken into account. In this manner, those studies turn their focus on examining the robustness of policy alternatives, rather on capturing risk factors. Cohen & Lee [7], Arntzen et al. [2] and Sabri & Beamon [15] jointly provide great support in this regard. However, unfortunately, even there indeed exists convinced reasons for continuing the development of deterministic models, stochastic models are much more worth deployed in the recent years. In other words, because numerous types of uncertainty result in intensive, negative effects on SC performance in nowadays business environment, studies such as Cohen & Lee [6] and Lee & Billington [14] initiated the applications of stochastic models in logistics management for highlighting the nature and effects from dynamics and violation. Therefore, in the next section, the logistics models embedded with uncertain considerations are reviewed.

2.2 How Uncertainty Is Identified and Modeled in Global Logistics Systems

From practice perspective, a SC is composed of a series of workflows between and within firms. The loop of those workflows, in short, starts at the forecasting that is based upon historical consumption records, followed by material purchase, components delivery, as well as product manufacturing, and finally ended by order fulfillment and shipments to customers [8]. This cycle, in general, repeats itself up and down in the SC iteratively. By tracing and diagnosing these operations embedded in this endless, repeated cycle, Davis [8] and Lee & Billington [14] identify three distinct sources of uncertainties or variability, which are cited as keys to effective SCM. The first cause is ‘supplier performance.’ A supplier quotes a lead time but is always hard to provide raw materials to its downstream on time, even when the due day is promised in advance. Thus, such a situation, in turn, leads downstream players tend to hold excess stocks as means to keep whole manufacturing process running reliably.

The second source that amplifies the variability of a SC is ‘manufacturing process’ itself. Lots of problems may stop material flows and lead to unstable manufacturing processes. This phenomenon holds true especially when key workers are tied up by other jobs, machines break down unexpectedly, or computers foul up. Finally, ‘customer demand’ is the last source that results in uncertainty in a SC [Davis, 1993; Lee & Billington, 1993; Flaherty, 1996]. In most cases, the higher variation the customer orders they are, the more the safety stock it is required to be held. Therefore, due to the fickle demand of customers, the members in a SC have to be more reliable and flexible in an effort to overcome those challenges.

Unfortunately, although Davis [8] and Lee & Billington [14] highlight the effects of uncertainty on the effectiveness and the reliability of SCM and global logistics management, less attention is paid for this issue. For instance, according to Supply Chain

Council (SCC), it is surprisingly to find that the concept "uncertainty" is not clearly formulated in its definition on SC, which might imply that it still lacks significant position for this issue. Moreover, most effects resulting from uncertainties are modeled only by qualitative formats in literature. In other words, few studies take factors that cause uncertainty into account by quantitative means in logistics models [18]. As a consequence, Vidal & Goetschalckx [19] propose a mathematical model fulfilling such a request. In their study, uncertainties are modeled on supplier side. They deal with reliability issues on each supplier in the system by assigning a probability, which is calculated by how well a supplier delivers its shipments punctually and correctly.

Fairly speaking, this model offers a good starting point for analyzing and determining the effects of uncertainties in a global logistic system. However, Vidal & Goetschalckx [19] emphasize the reliability issues only on supplier side, which implies that the following issues are overlooked: (1) neglecting the effects of reliability on other players (such as manufacturers) in a global logistic system; and (2) less attention was paid to explaining how firms or SCs determine the tradeoffs between two critical concerns: overall system reliability and total cost. To make this mathematical model better describe the complete profile of a global logistic system, it, thus, calls for further extension by taking over the above drawbacks.

3. THE EXTENDED MODEL

This study aims to propose an extended model based upon Vidal & Goetschalckx's [19] model. In this extended model, concerns of reliabilities are not only on supplier side, but also on the remaining players in a global logistics system, which include factories, warehouses, and transportation channels. To clearly depict the value and emphases between Vidal & Goetschalckx's model and this proposed extended model, Table 1 makes a brief comparison between these two models. Besides, when management starts their debates on system reliability and cost, the tradeoff concerns between these two issues further force this extended model form a two-mode operation that fits the characteristic of duality: (1) cost minimization on a target of system reliability; and (2) system reliability maximization on a target of cost. In this section, basic settings for this extended model will be described firstly, followed by the detailed description of these two operation modes.

3.1 Basic Settings for the Extended Model

In order to be consistent with Vidal & Goetschalckx's [19] model, six key assumptions are made for this extended model: (1) only one time-period is considered; (2) there is only one end product, with one level decomposition in its bill of material (BOM); (3) costs of raw material delivery are not taken into account; (4) customer demands are determined and known in advance; (5) backlog order strategy is not allowed; and (6) there is no exchange rate fluctuation. In the followings, the indexes, parameters, and decision variables of this extended model are defined.

c = customer. f = factory.
r = raw material. s = supplier
w = warehouse. m = transportation mode.
C = set of customers. F = set of factories.
R = set of raw materials. S = set of suppliers.
W = set of warehouse.
M = set of transportation mode.
P_{srf} = reliability of supplier s to factory f.
P_{fmw} = reliability of factory f to warehouse w.

Table 1: A comparison between Vidal & Goetschalckx's (2000) and the extended model

	Vidal & Goetschalckx's Model	***The Extended Model***
Research Focus	being the first that models uncertain functions on global logistics systems	1) providing a reference model for setting uncertain functions on all players in global logistics systems 2) address the trade-off concerns on system cost and system reliability
Reliability Concerning	only on supplier layer	on all components of logistic systems (e.g., suppliers, factories, warehouses and transportation channels)
Formulation	Min. Cost s.t. Required Reliability	Mode 1: Min Cost s.t. Required Reliability Mode 2: Max Reliability s.t. Restricted Budget / Cost
Expected Contribution	exploring how and what to model uncertainty in global logistics systems	1) illustrating how to model uncertainty on all players in the logistics systems 2) beneficial for firms that try to find out a great portfolio between multi-objective functions

P_{wmc} = reliability of warehouse *w* to customer *c*.
Dc = demand of customer *c*.
E_f = exchange rate that factory *f suffers*.
E_s = exchange rate that supplier *s suffers*.
E_w = exchange rate that warehouse *w suffers*.
MNC_f = production cost of end product in factory *f*.
FIX_f = fix cost of factory *f*.
RICfr = unit holding cost of raw material r in factory f.
MNP_f = production capacity of factory *f*.
M(f,w) = set of transportation mode from factory $f \in F$ *to warehouse* $w \in W$, $M(f,w) \subseteq M$.
M(w,c) = set of transportation mode from warehouse $w \in W$ *to customer* $c \in C$, $M(w,c) \subseteq M$.
PRC_{sr} = *procurement cost of raw material r from supplier s.*
RIA_{fr} = *required inventory of raw material r in factory f.*
RIL_{fr} = *required inventory level of raw material r in factory f.*
EIC_f = unit holding cost of end product in factory *f*.
EIA_f = inventory amount of end product in factory *f*.
EIC_w = unit holding cost of end product in warehouse *w*.
EIA_w = inventory of end product in warehouse *w*.
TRC_m = shipping cost of transport mode *m*.
TRP_m = shipping capacity of transport mode *m*.
WP_w = capacity of warehouse *w*.
WL_w = required inventory level of end product in warehouse *w*.
BOM_r = quantity of raw material *r* needed for manufacturing an end product.
PT = target reliability to fulfillment customers' need.
COST = affordable cost to fulfillment customers' need.
RA_{srf} = quantity of raw material *r*, shipped from supplier *s* to factory *f*.
MNA_f = quantity of end product manufactured in factory *f*.
TRA_{fmw} = quantity of shipment from factory *f* to warehouse *w* using transportation mode *m*.
TRA_{wmc} = quantity of shipment from warehouse *w* to customer *c* using transportation mode *m*.
V_s = 1, if supplier *s* ships raw material; 0 otherwise.
X_f = 1, if factory *f* is opened; 0 otherwise.
Z_w = 1, if warehouse *w* is used; 0 otherwise.
V_{srf} = 1, if supplier *s* ships raw material *r* to factory *f*; 0 otherwise.
V_{fmw} = *1, if* factory *f ships products by transaction mode m to warehouse w; 0 otherwise.*
V_{wmc} = 1, if warehouse *w* ships products by transaction mode *m* to customer *c*; 0 otherwise.

3.2 Two Modes of this Extended Model

3.2.1 Mode 1: seeking minimum cost on a target of system reliability

Mode 1 assumes total cost as the most important decision variable for firms. More specifically, in this operation model, the objective function is to minimize total cost of the logistics system, which is the sum of costs of raw material procurement, fixed costs of factory opening, manufacturing costs, inventory costs of raw materials and end products, and transportation cost. Further, the constraints of this model include factory capacity, inventory level of raw material in factory, transportation channel capacity, customer demand satisfaction, inventory of end products, and required reliability level (i.e., constraints from C1 to C18).

Min. Total system cost

= Costs of raw material procurement + Fixed cost of opening factories + Manufacturing cost + Inventory cost (raw materials in factory, products in factory and in warehouse) +Transportation cost (factory to warehouse, arehouse to customer)

$$= \sum_{s\in S}\sum_{r\in R}\sum_{f\in F}\left(\frac{1}{E_s}\right) PRC_{sr} \cdot RA_{srf} + \sum_{f\in F}\left(\frac{1}{E_f}\right) FIX_f \cdot X_f + \sum_{f\in F}\left(\frac{1}{E_f}\right) MNC_f \cdot MNA_f + \left[\sum_{f\in F}\sum_{r\in R}\left(\frac{1}{E_f}\right) RIC_{fr} \cdot RIA_{fr} + \sum_{f\in F}\left(\frac{1}{E_f}\right) EIC_f \cdot EIA_f + \sum_{w\in W}\left(\frac{1}{E_w}\right) EIC_w \cdot EIA_w\right] + \left[\sum_{f\in F}\sum_{m\in M}\sum_{w\in W}\left(\frac{1}{E_f}\right) TRC_m \cdot TRA_{fmw} + \sum_{w\in W}\sum_{m\in M}\sum_{c\in C}\left(\frac{1}{E_w}\right) TRC_m \cdot TRA_{wmc}\right]$$

S.T.

$$MNA_f \le MNP_f, \quad f\in F; \qquad \text{(C1)}$$
$$RIA_{fr} \ge RIL_{fr}, \quad f\in F, r\in R; \qquad \text{(C2)}$$
$$\sum_{f\in F}\sum_{w\in W} TRA_{fmw} \le TRP_m, \quad m\in M; \qquad \text{(C3)}$$
$$\sum_{w\in W}\sum_{c\in C} TRA_{wmc} \le TRP_m, \quad m\in M; \qquad \text{(C4)}$$
$$\sum_{w\in W}\sum_{m\in M} TRA_{wmc} = D_c, \quad c\in C; \qquad \text{(C5)}$$
$$EIA_w \le WP_w, \quad w\in W; \qquad \text{(C6)}$$
$$EIA_w \ge WL_w, \quad w\in W; \qquad \text{(C7)}$$
$$RA_{srf} \le PRP_{sr} * V_{srf}, \quad s\in S, r\in R, f\in F; \qquad \text{(C8)}$$
$$V_{srf} \le V_s, \quad s\in S, r\in R, f\in F; \qquad \text{(C9)}$$
$$MNA_f \le MNP_f * X_f, \ \forall f \in F; \qquad \text{(C10)}$$
$$V_{fmw} \le X_f, \quad \forall w\in W, m\in M, f\in F; \qquad \text{(C11)}$$

$TRA_{fmw} \leq TRP_{fmw} * V_{fmw}$, $\forall f \in F, m \in M, w \in W$; (C12)

$V_{fmw} \leq Z_w$, $\forall w \in W, f \in F, m \in M$; (C13)

$TRA_{wmc} \leq TRP_{wmc} * V_{wmc}$, $\forall m \in M, w \in W, c \in C$; (C14)

$V_{wmc} \leq Z_w$, $\forall w \in W, c \in C, m \in M$; (C15)

$$\prod_{s \in S} \prod_{r \in R} \prod_{f \in F} \prod_{m \in M} \prod_{w \in W} \prod_{c \in C} (P_{srf})^{Vsrf} \cdot (P_{fmw})^{Vfmw} \cdot (P_{wmc})^{Vwmc} \geq PT; \quad (C16)$$

$V_s, X_f, Z_w \in \{0,1\}$, $s \in S, f \in F, w \in W$; (C17)

$V_{srf}, V_{fmw}, V_{wmc}, \in \{0,1\}$, $s \in S, r \in R, f \in F, m \in M, w \in W, c \in C$; (C18)

3.2.2 Mode 2: seeking maximum system reliability on a target of cost

Opposite to Mode 1, Mode 2 regards system reliability as the primal decision variable for firms in the logistics system. The objective function, therefore, is to maximize the overall system reliability, which is modified from the constraint C16 of Mode 1. Meanwhile, constraints of Mode 2 are the same with those of Mode 1, except for the constraint C16', which is newly added and is modified from the objective function of Mode 1, representing the upper bound of allowed cost expenditure.

Max. Overall system reliability

= The product of reliability of all components operated in a global logistic system

$$= \prod_{s \in S} \prod_{r \in R} \prod_{f \in F} \prod_{m \in M} \prod_{w \in W} \prod_{c \in C} (P_{srf})^{Vsrf} \ (P_{fmw})^{Vfmw} \ (P_{wmc})^{Vwmc}$$

S.T.

$MNA_f \leq MNP_f$, $f \in F$; (C1)

$RIA_{fr} \geq RIL_{fr}$, $f \in F, r \in R$; (C2)

$\sum_{f \in F} \sum_{w \in W} TRA_{fmw} \leq TRP_m$, $m \in M$; (C3)

$\sum_{w \in W} \sum_{c \in C} TRA_{wmc} \leq TRP_m$, $m \in M$; (C4)

$\sum_{w \in W} \sum_{m \in M} TRA_{wmc} = D_c$, $c \in C$; (C5)

$EIA_w \leq WP_w$, $w \in W$; (C6)

$EIA_w \geq WL_w$, $w \in W$; (C7)

$RA_{srf} \leq PRP_{sr} * V_{srf}$, $s \in S, r \in R, f \in F$; (C8)

$V_{srf} \leq V_s$, $s \in S, r \in R, f \in F$; (C9)

$MNA_f \leq MNP_f * X_f$, $\forall f \in F$; (C10)

$V_{fmw} \leq X_f$, $\forall w \in W, m \in M, f \in F$; (C11)

$TRA_{fmw} \leq TRP_{fmw} * V_{fmw}$, $\forall f \in F, m \in M, w \in W$; (C12)

$V_{fmw} \leq Z_w$, $\forall w \in W, f \in F, m \in M$; (C13)

$TRA_{wmc} \leq TRP_{wmc} * V_{wmc}$, $\forall m \in M, w \in W, c \in C$; (C14)

$V_{wmc} \leq Z_w$, $\forall w \in W, c \in C, m \in M$; (C15)

$$\sum_{s \in S} \sum_{r \in R} \sum_{f \in F} (\frac{1}{E_s}) PRC_{sr} \cdot RA_{srf} + \sum_{f \in F} (\frac{1}{E_f}) FIX_f \cdot X_f + \sum_{f \in F} (\frac{1}{E_f}) MNC_f \cdot MNA_f + \sum_{f \in F} \sum_{r \in R} (\frac{1}{E_f}) RIC_{fr} \cdot RIA_{fr} + \sum_{f \in F} (\frac{1}{E_f}) EIC_f \cdot EIA_f + \sum_{f \in F} \sum_{m \in M} \sum_{w \in W} (\frac{1}{E_f}) TRC_m \cdot TRA_{fmw} + \sum_{w \in W} (\frac{1}{E_w}) EIC_w \cdot EIA_w + \sum_{w \in W} \sum_{m \in M} \sum_{c \in C} (\frac{1}{E_w}) TRC_m \cdot TRA_{wmc} \leq COST \quad (C16')$$

$V_s, X_f, Z_w \in \{0,1\}$, $s \in S, f \in F, w \in W$; (C17)

$V_{srf}, V_{fmw}, V_{wmc}, \in \{0,1\}$, $s \in S, r \in R, f \in F, m \in M, w \in W, c \in C$; (C18)

4. THE EXPERIMENT AND ITS RESULTS

To validate the appropriateness of this extended model, as well as to investigate the implicit relationship between overall system reliability and total cost of a global logistics system, experiments on a simplified four-echelon global logistics structure are done in this study. The configuration of this experiment is depicted in Figure 1, a modified version of Vidal & Goetschalckx [19]. Detailed scenario, data set, parameters and settings are summarized as follows:

1. The end product is made of two types of raw materials, R1 and R2. As Figure 2 depicts, the BOM structure of the end product, in short, illustrates that it requires one unit R1 and two units R2 to produce one end product.
2. Four suppliers (i.e., S1, S2, S3 and S4) are in this logistics system. S1 and S2 provide raw material R1; whereas S3 and S4 provide raw material R2. As shown in Table 2, in order to simulate the cases in the real world, the procurement cost (from \$8 to \$20 per unit) and reliability level (from 0.992 to 0.999) of suppliers are set entirely different from one to another in this experiment.
3. There are two factories taking over the task of product manufacturing. Each factory requires a fixed but different operating cost; meanwhile, the quantity a factory manufactures cannot exceed its capacity. Table 3 provides relevant numbers and information.

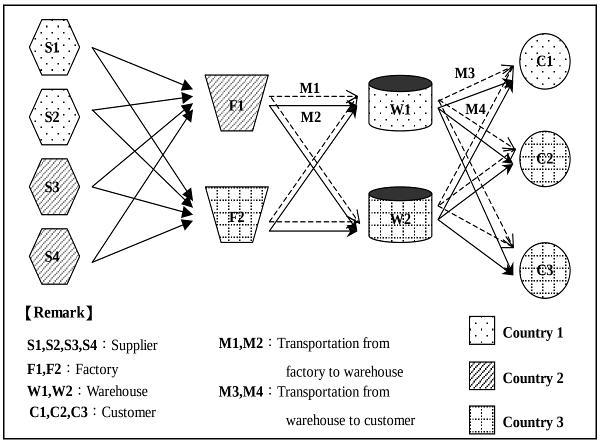

Figure 1: The configuration of the experiment

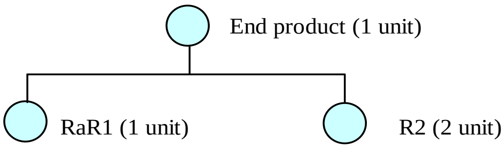

Figure 2: BOM structure

4. Two warehouses are involved in this logistics system, acting the role of inventory storage (for end products). As Table 4 illustrates, each warehouse has its own holding cost structure, reliability level for flawless storing, and maximum allowance quantity of inventory.
5. More than one alternative can be chosen in each delivery stage. In particular, for the stage shipping products from factory to warehouse, two transportation channels (M1 and M2) are offered. Similarly, for the stage shipping products from warehouse to customer, there exist another two transportation channels (M3 and M4) for choice. Because each transportation channel has its own strengths and weaknesses (e.g., in regard to the efficiency of time and cost), the transportation cost per unit and the reliability level for on-time transportation varies between channels, as depicted in Table 5 and Table 6.
6. The all components' reliabilities are depicted in Table 7.

Table 2: Parameters of suppliers

Supplier	*Procurement cost (Material type)*
#1	$10 / unit (R1)
#2	$8 / unit (R1)
#3	$20 / unit (R2)
#4	$16 / unit (R2)

Table 3: Parameters of factories

Factory	*Fixed cost for opening*	*Manufacturing cost*	*Capacity*
#1	$5,000	$50 / unit	2,000 / unit
#2	$4,000	$40 / unit	1,500 / unit

Table 4: Parameters of warehouses

Warehouse	*Inventory holding Cost*	*Capacity*
#1	$10 / unit	2,000 / unit
#2	$8 / unit	2,000 / unit

Table 5: Parameters of transportation channels from factory to warehouse

Unit cost	*Warehouse 1 M1 (M2)*	*Warehouse 2 M1 (M2)*
Factory 1	$19 ($20)	$18 ($19)
Factory 2	$17 ($18)	$16 ($17)

Table 6: Parameters of transportation channels from warehouse to customer

Unit cost	*Customer 1 M3(M4)*	*Customer 2 M3(M4)*	*Customer 3 M3(M4)*
Warehouse 1	$32 ($34)	$28 ($30)	$31 ($33)
Warehouse 2	$43 ($45)	$42 ($44)	$39 ($41)

Table 7: Parameters of reliability

Parameters	Reliability	Parameters	Reliability
P_{s1r1f1}	0.998	P_{s1r1f2}	0.997
P_{s2r1f2}	0.995	P_{s2r1f1}	0.997
P_{s3r2f1}	0.996	P_{s3r2f2}	0.997
P_{s4r2f1}	0.998	P_{s4r2f2}	0.996
P_{f1m1w1}	0.993	P_{f1m2w1}	0.994
P_{f1m1w2}	0.994	P_{f1m2w2}	0.995
P_{f2m1w1}	0.997	P_{f2m1w2}	0.993
P_{f2m2w1}	0.992	P_{f2m2w2}	0.993
P_{w1m3c1}	0.995	P_{w1m3c2}	0.998
P_{w1m3c3}	0.995	P_{w1m4c1}	0.998
P_{w1m4c2}	0.997	P_{w1m4c3}	0.997
P_{w2m3c1}	0.994	P_{w2m3c2}	0.993
P_{w2m3c3}	0.996	P_{w1m4c2}	0.995
P_{w2m4c1}	0.994	P_{w2m4c3}	0.994

The experiment results based upon Mode 1 and Mode 2 are plotted in Figure 3 and Figure 4. Both figures show the positive relation between required system reliability and allowed cost level (i.e., the higher the reliability the firm requires, the higher the cost it has to spend), as suggested in literature.

However, such a relation is non-linear. As a consequence, thresholds are found in both figures. In Figure 3, for instance, the threshold of system reliability is 0.96, which means when the target reliability is lower than 0.96, it charges cheaper price (or lower marginal cost) for improving system reliability, in comparison with the case the target reliability exceeds 0.96. Similarly, in Figure 4, the pattern implies that if cost expenditure reaches the threshold (i.e., 200000), the overall system reliability will be improved slightly, even when a firm is willing to invest a number of extra target cost.

From practical perspective, the above phenomenon seems to suggest that when decision makers try to balance between two tradeoffs namely system reliability and total cost, more considerations and analyses are required. In other words, how to efficient and properly apply these two-mode operations embedded in this extended model interactively and appropriately, will be the key to ensure the efficiency and reliability when planning a global logistics system.

5. CONCLUSION

In order to provide a mathematical model with thoroughly considerations on depicting the required cost expenditure in dealing with uncertainty in a logistics system, this paper extends Vidal & Goetschalckx's [19] model by adding complete reliability settings on all components in a global logistic system. Meanwhile, to help firms easily get a balance between two tradeoff decision variables, overall system reliability and total cost of a logistics system, two operation modes with dual concerns are proposed: (1) Mode 1: seeking minimum cost on a target of system reliability; and (2) Mode 2: seeking maximum system reliability on a target of cost.

The feasibility of this extended model is then examined by experiments on a simplified four-echelon global logistics structure. From the results, these dual operation modes are proved to be able to provide more insights and detailed information for management, when determining how to build up an efficient and reliable global logistics system. Beyond that, the results also reveal that due to the positive but non-linear relation lying between overall system reliability and total cost, thresholds exist, which means: (1) the cost for improving system reliability will increase dramatically, when the target of reliability exceeds the threshold; or (2) a firm needs to spend relatively more marginal cost in improving system reliability when its reliability level is beyond the threshold.

Table 1 shortly concludes the goals and the

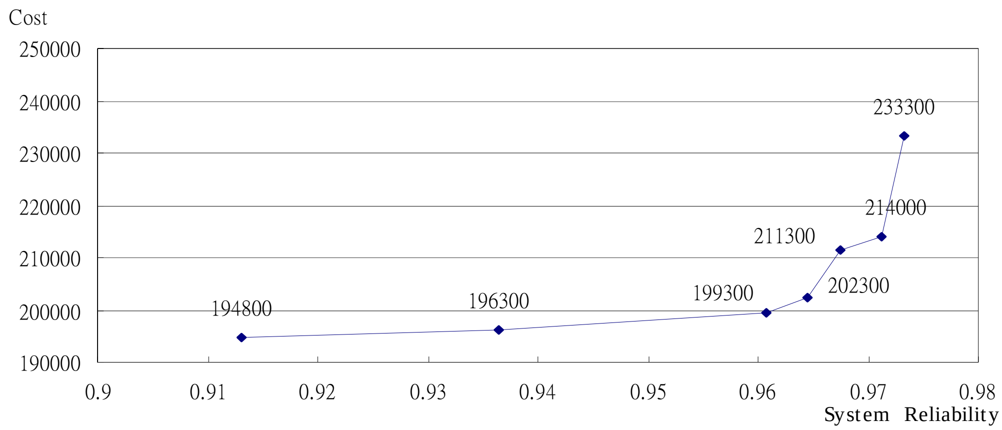

Figure 3: Experiment results of mode 1

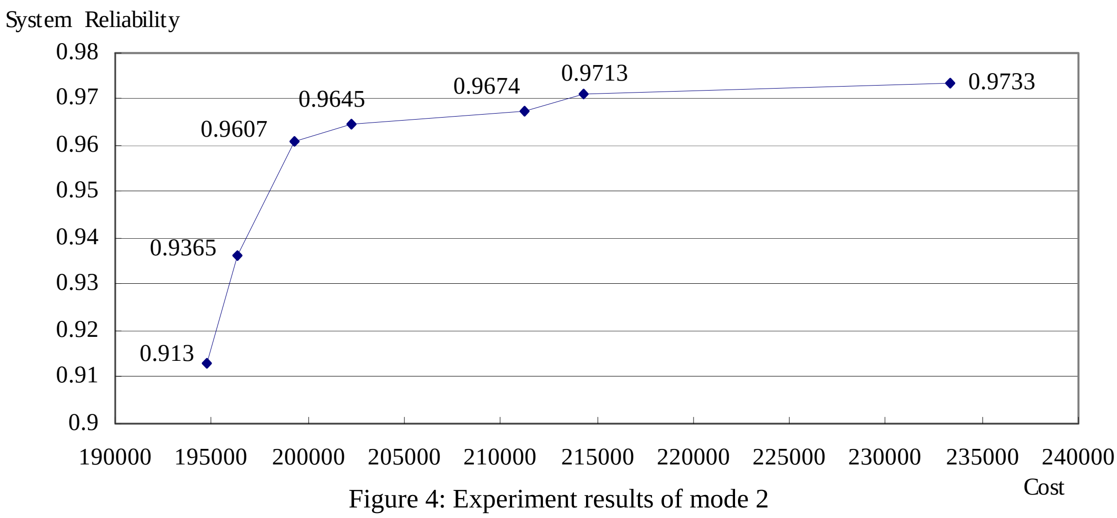

Figure 4: Experiment results of mode 2

value of the work in this paper. To sum up, this study contributes to both academy and management. On one hand, for the academy aspect, this study proposes an extended model which provides a better quantitative reference base for the overall plan of a logistics system, by adding wider reliability settings on all players in the system. On the other hand, for the practice, the two-mode (or dual) operations are believed to be helpful for managers in determining a great balance between overall system reliability and total cost in an efficient manner, by utilizing the outcomes of Mode 1 and Mode 2 (i.e., plotting the pairs of given level of reliability and its corresponding cost by changing the conditions or boundary of constraint C16 in Mode 1 or C16' in Mode 2).

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